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RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

FLIGHT CHARACTERISTICS AT LOW SPEED OF A $\frac{1}{12}$-SCALE MODEL OF THE CONSOLIDATED VULTEE 7002 AIRPLANE (FLYING MOCK-UP OF XP-92)

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

An investigation of the low-speed, power-off stability and control characteristics of a $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane (a flying mock-up of the XP-92 airplane) has been conducted in the Langley free-flight tunnel. The results of the investigation showed that the longitudinal stability was fairly good and the longitudinal control was adequate over the entire speed range covered which included stalls. There was, however, an unusual response of the model glide angle to longitudinal control which at times produced the opposite motion to that desired. The lateral stability of the model over most of the speed range was good but the damping of the rolling oscillations decreased somewhat with an increase in lift coefficient. The lateral control was good at all speeds below the stall when the rudder was linked to move with the elevons for lateral control. At angles of attack near the stall the lateral control was generally effective enough so that control of the model could be maintained, but the control effectiveness was undesirably low. When elevons alone were used for lateral control, the general flight behavior was fairly good for lift coefficients below 0.74 but was unsatisfactory for higher lift coefficients.

INTRODUCTION

An investigation of the low-speed, power-off stability and control characteristics of a $\frac{1}{12}$-scale dynamic free-flying model of the Consolidated Vultee 7002 airplane has been conducted in the Langley free-flight tunnel at the request of the Air Materiel Command, U.S. Air Force. The

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purpose of this investigation was to make a qualitative evaluation of the flight characteristics of the airplane before flight tests of the full-scale airplane were made.

The Consolidated Vultee 7002 jet-propelled airplane is a flying mock-up of the XP-92 fighter airplane. The airplane has a wing of triangular plan form with 60° sweepback of the leading edge, an aspect ratio of 2.31, and a taper ratio of 0 and a vertical tail of 60° swept-back triangular plan form but no horizontal tail. Longitudinal and lateral control are provided by elevons, which are a single set of trailing-edge control surfaces on the wing, and a rudder. Deflecting the elevons together gives longitudinal control and deflecting them differentially gives lateral control. The fuselage on the Consolidated Vultee 7002 airplane is somewhat smaller and of a different shape from that of the XP-92.

SYMBOLS

All forces and moments were referred to the stability axes which are defined in figure 1. The rolling, yawing, and pitching moments were referred to the design center-of-gravity location which is at the quarter-chord point of the mean aerodynamic chord. The symbols and coefficients used in the present paper are:

S wing area, square feet

$\bar{c}$ mean aerodynamic chord, feet

b wing span, feet

q dynamic pressure, pounds per square foot

α angle of attack of fuselage center line, degrees

β angle of sideslip, degrees

ψ angle of yaw, degrees

C_L lift coefficient (Lift/qS)

C_D drag coefficient (Drag/qS)

C_m pitching-moment coefficient (Pitching moment/$qS\bar{c}$)

C_n yawing-moment coefficient (Yawing moment/qSb)

C_l rolling-moment coefficient (Rolling moment/qSb)

C_Y lateral-force coefficient (Lateral force/qS)

δ_e elevon deflection, degrees (subscripts r and l indicate right and left elevon, respectively)

δ_r rudder deflection, degrees

C_{Y_β} rate of change of lateral-force coefficient with angle of sideslip in degrees $\left(\partial C_Y/\partial\beta\right)$

C_{n_β} rate of change of yawing-moment coefficient with angle of sideslip in degrees $\left(\partial C_n/\partial\beta\right)$

C_{l_β} rate of change of rolling-moment coefficient with angle of sideslip in degrees $\left(\partial C_l/\partial\beta\right)$

APPARATUS AND TESTS

A three-view drawing of the $\frac{1}{12}$-scale model used in the present investigation is presented in figure 2 and photographs of the model are given in figures 3 and 4. The physical characteristics of the airplane and of the model scaled up to full scale are presented in table I.

The airfoil section used on the free-flight-tunnel model was a flat plate with a radius nose and a beveled trailing edge. (See fig. 2.) The wing of the model had the same ratio of maximum thickness to root chord as that of the Consolidated Vultee 7002 airplane and the wing tapered in thickness spanwise at the rate of 0.048 inch per inch. The vertical tail had a constant thickness of 0.25 inch, a radius nose, and a beveled trailing edge. These flat-plate airfoil sections were used on the wing and tail of the free-flight-tunnel model for simplicity in construction. The use of these sections was considered permissible because the aerodynamic characteristics of delta wings are virtually independent of the airfoil section at low scale. This characteristic has been established by comparison of the aerodynamic characteristics of some flat-plate delta wings from reference 1 with some German data on delta wings (reference 2) having NACA 0012 airfoil section and with some unpublished data on a 60° delta wing with an NACA 0015-64 airfoil section.

A complete description of the Langley free-flight tunnel and its operation is given in reference 3.

Flight tests were made to determine the stability and control characteristics and the general flight behavior of the model. General flight behavior is the term used to describe the over-all flying characteristics of the model and indicates the ease with which the model can be flown, both in straight level flight and in the mild maneuvers possible in the Langley free-flight tunnel. In effect, the general flight behavior is much the same as the pilot's opinion or "feel" of an airplane and indicates whether stability and controllability are adequate and properly proportioned.

Flight tests were made over a speed range corresponding to a range of lift coefficients from 0.49 to the stall with the center of gravity at the normal position (25 percent of the mean aerodynamic chord). For some tests, the center of gravity was moved progressively rearward from 25 to 30 percent of the mean aerodynamic chord, which corresponded to static margins from about 12.3 to 3.3 percent of the mean aerodynamic chord, with the model flying at a lift coefficient of about 0.75.

Most of the flight tests were made at a light loading (table I) in order to minimize damage to the model in crack ups. After the flight conditions had been established with the model in the light condition, some of the tests were repeated at the normal loading. This normal loading corresponded to the loading of the CV-7002 airplane at its normal gross weight.

Force tests to determine the aerodynamic characteristics of the model were made on the Langley free-flight-tunnel six-component balance which is described in reference 4. All of the force tests were made at a dynamic pressure of 3.0 pounds per square foot which corresponds to a Reynolds number of approximately 483,000 based on the wing mean aerodynamic chord.

The primary purpose of these force tests was to determine how well the aerodynamic characteristics of the free-flight-tunnel model might be expected to represent those of the full-scale airplane. This was done by comparing the static stability characteristics of the free-flight-tunnel model with those obtained from higher scale tests ($R = 2.16 \times 10^6$) on the same size model conducted at GALCIT (Guggenheim Aeronautical Laboratory, California Institute of Technology). For the comparison, tests were made through the angle-of-attack range to determine the static longitudinal stability and control characteristics and through the yaw range to determine the static lateral stability characteristics of the model at angles of attack near the stall.

Tests were also made to determine the variation of the static lateral stability parameters C_{Y_β}, C_{n_β}, and C_{l_β} with lift coefficient. The values of these stability parameters were determined from the difference between the force and moment coefficients at 5° and -5° yaw. Force tests were also made to determine the rolling effectiveness of the elevons when they were trimmed up to provide longitudinal trim for lift coefficients of 0.52 and 0.72.

RESULTS AND DISCUSSION

Results of force tests and comparison of the aerodynamic characteristics of the free-flight-tunnel model with those of the GALCIT model (figs. 5 to 11) show reasonable similarity of the important stability parameters. The static longitudinal stability $\frac{\partial C_m}{\partial C_L}$ and the stability at the stall in terms of $\partial C_m/\partial \alpha$ are about the same for both models. (See fig. 5.) The maximum lift coefficient of the free-flight-tunnel model was about 10 percent lower than that shown by the higher scale tests at GALCIT. Comparison of the stability in yaw at an angle of attack of 28° for the free-flight-tunnel model and 25° for the GALCIT model (fig. 9) shows fair agreement between the stability of the two models at these angles of attack which correspond to about 95 percent of maximum lift. (See fig. 5.) GALCIT data at higher angles of attack than 25° were not available for comparison with the other free-flight-tunnel data presented in figure 9. The free-flight-tunnel test results given in figure 10 show approximately the same amount of directional stability and considerably smaller values of effective dihedral over the angle-of-attack range for the -5° to +5° yaw conditions than is shown by the GALCIT data.

The elevon pitching and rolling effectiveness tests for the free-flight-tunnel model are compared in figures 7 and 11 with higher scale test data on the GALCIT model with wing leading edge "dorsals," since there were no available GALCIT elevon-effectiveness data for the dorsals-off configuration. These "dorsals" are shown in dashed lines in the sketch of the model (fig. 2). The pitching and rolling effectiveness of the elevons of the free-flight model were about the same as that shown in the GALCIT tests (figs. 7 and 11) at low lift coefficients and small control deflections. At high lift coefficients or control deflections, however, the controls of the free-flight-tunnel model were weaker than those of the GALCIT model.

Longitudinal Stability and Control

The longitudinal stability and control characteristics of the free-flying model were fairly good over the entire speed range covered in the tests which included stalls. The longitudinal characteristics of this model were not as good as those of a good conventional model because of a slight unsteadiness and an unusual response of the model to longitudinal control. This unsteadiness may have been caused by unsteadiness of the flow over the wing. The air going over the wing separates from the surface at the leading edge of the wing and forms two large vortices which rotate downward at the center of the model and upward at the wing tips. This type of flow has been observed by smoke-flow tests on a delta wing in the Langley full-scale tunnel (reference 5) and by flight tests in the free-flight tunnel of another delta-wing model with streamers of string attached to the upper surface of the wing.

The unusual response of the model to longitudinal control was the principal source of difficulty in flying the model. This was apparently associated with a large variation of drag with lift which is generally a characteristic of low-aspect-ratio swept wings. This large variation of drag with lift causes large variations of glide angle with lift coefficient (fig. 8) since the trim glide angle is a function of the drag-lift ratio. The minimum glide angle also occurs at a fairly low lift coefficient $\left(C_L = 0.32\right)$ for the model instead of near the stall as with conventional models. All of the tests of the present investigation were flown at lift coefficients above that corresponding to the minimum glide angle. In this speed range, deflecting the elevator downward caused the glide angle to be steeper for a short time until the speed of the model increased and approached the new trim speed. The glide angle then became flatter as the model approached the new trim condition. The opposite dynamic behavior followed an upward elevator deflection; that is, the glide angle at first was flatter and then became steeper as the new trim condition was approached. At times this characteristic was very troublesome to the pilot because of the difficulty it caused in determining in which direction to move the elevator to cause the model to move up or down within the tunnel. A brief deflection of the elevator caused one effect, whereas holding that deflection caused the opposite effect. Although no flights of the model were made at lift coefficients below that corresponding to the minimum glide angle $\left(C_L = 0.32\right)$ because of the limited tunnel airspeed, tests of lighter delta-wing models reported in reference 6 indicate that the response of the CV 7002 model would probably be normal in this condition. The significance of this unusual response to the elevator has not been definitely determined but it is the opinion of the NACA airplane test pilots that such behavior would be definitely objectionable to the pilot of a full-scale airplane.

The power-off glide angles at high lift coefficients were very steep - a characteristic which might cause trouble in power-off landings.

The maximum lift coefficient obtained in steady flight was 0.75 at an angle of attack of about 32°. The stall occurred at an angle of attack of about 38° and the model settled gently to the tunnel floor without any tendency to nose up. The elevons were still effective for pitching the model when the model stalled.

As the center of gravity was moved rearward from 0.25 to 0.30 mean aerodynamic chord at a lift coefficient of about 0.70, the model became more sensitive to elevator control; and there was a reduction in the static and dynamic longitudinal stability and an increase in the elevator effectiveness. This reduction in stability and increase in elevator sensitivity, however, did not have too great an effect on the longitudinal steadiness and the flight behavior was fair even with the center of gravity at 0.30 mean aerodynamic chord which corresponded to a static margin of about 0.03.

There was no apparent difference in the longitudinal stability, control, or general flight behavior of the model caused by the change from the light to the heavy loading over the range covered in the flight tests (table I).

Lateral Stability and Control

The model could be flown fairly well at all speeds below the stall when the rudder was linked to move with the elevons for lateral control. At the stall there were noticeable yawing motions and a slight tendency for the model to roll off but this roll off could generally be controlled by use of the elevons and rudder although the elevon effectiveness was fairly low as shown in figure 11.

When the elevons alone were used for lateral control, the model could be flown fairly well at lift coefficients below 0.70. As the lift coefficient was increased above a value of 0.70, however, the flight behavior of the model rapidly became worse until the model was unflyable at a lift coefficient of 0.74 with the elevons alone used for control. The cause of this sudden deterioration of the flight behavior was evidently due to a sharp drop in directional stability at this point. This sudden decrease in directional stability is indicated in figure 10 to begin at an angle of attack of 28° which was the angle of attack corresponding to a lift coefficient of 0.70 as measured in flight. The low directional stability at angles of attack above 28° allowed the adverse yawing due to elevon deflection to become pronounced so that the high effective dihedral caused adverse rolling moments when the elevons alone were used for control. These adverse rolling moments reduced the already low rolling effectiveness of the elevons (shown in fig. 11) and thereby caused the model to be virtually uncontrollable with elevons alone at lift coefficients above 0.70.

The dynamic lateral stability of the model over most of the speed range including the stall was good but appeared to decrease with an increase in lift coefficient. At the high lift coefficients there were small-amplitude rolling oscillations which persisted for a few cycles after disturbances. This motion was probably the familiar Dutch roll oscillation with the rolling more pronounced in this case because of the relatively high effective dihedral and low damping in roll. The yawing motions of the model became slightly worse as the angle of attack was increased but there was no evidence of a directional divergence at angles of attack between 32° and 38° as indicated by the directional stability parameter $C_{n_{\beta}}$ in figure 10. Stability theory shows that an airplane can be directionally stable with three degrees of lateral freedom even though $C_{n_{\beta}}$ is negative, provided that the dihedral effect is positive. This fact is generally obscured, however, because most airplanes become uncontrollable as $C_{n_{\beta}}$ approaches zero when there is definite positive dihedral effect. This was the case with the CV 7002 model when the elevons alone were used for lateral control.

There was no apparent effect on the lateral stability, control, or general flight behavior of changes in loading from the light to normal loading shown in table I.

CONCLUSIONS

The following conclusions were drawn from the results of the free-flight-tunnel stability and control investigation of the Consolidated Vultee 7002 airplane:

1. The longitudinal stability of the model was fairly good over the entire speed range covered in the tests which included stalls.

2. The elevator effectiveness was adequate for longitudinal control over the entire speed range including the stall. There was, however, an unusual response of the model glide angle to longitudinal control which at times produced the opposite motion that was desired.

3. The lateral stability of the model over most of the speed range was good but the damping of the rolling oscillations decreased somewhat with an increase in lift coefficient.

4. The lateral control was good at all speeds below the stall when the rudder was linked to move with the elevons for lateral control. At angles of attack at the stall the control was effective

enough so that control of the model could generally be maintained although the control effectiveness was rather low. When elevons alone were used for lateral control, the general flight behavior was fairly good for lift coefficients below 0.74 but was unsatisfactory for higher lift coefficients.

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2. Lange and Wacke: Prüfbericht über 3- und 6-Komponentenmessungen an der Zuspitzungsreihe von Flügeln kleiner Streckung. Teilbericht: Dreieckflügel. UM Nr. 1023/5, Deutsche Luftfahrtforschung (Berlin-Adlershof), 1943. (Available as NACA TM No. 1176, 1948.)

3. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. NACA TN No. 810, 1941.

4. Shortal, Joseph A., and Draper, John W.: Free-Flight-Tunnel Investigation of the Effect of the Fuselage Length and the Aspect Ratio and Size of the Vertical Tail on Lateral Stability and Control. NACA ARR No. 3D17, 1943.

5. Wilson, Herbert A., Jr., and Lovell, J. Calvin: Full-Scale Investigation of the Maximum Lift and Flow Characteristics of an Airplane Having Approximately Triangular Plan Form. NACA RM No. L6K20, 1946.

6. McKinney, Marion O., Jr., and Drake, Hubert M.: Flight Characteristics at Low Speed of Delta-Wing Models. NACA RM No. L7K07, 1947.

TABLE I.- DIMENSIONAL AND MASS CHARACTERISTICS OF THE CONSOLIDATED VULTEE 7002 AIRPLANE AND SCALED-UP CHARACTERISTICS OF THE $\frac{1}{12}$-SCALE MODEL TESTED IN THE LANGLEY FREE-FLIGHT TUNNEL

	Scaled-up		Full Scale
	Light	Heavy	
Weight, lb	9,150	11,560	11,600
Wing loading, lb/sq ft	21.5	27.2	27.3
Moments of Inertia, slug-ft^2			
I_X	4,070	4,070	4,110
I_Y	24,350	27,300	27,283
I_Z	26,900	29,750	29,641

	Scaled-up	Full Scale
Wing:		
Area, sq ft	425	425
Span, ft	31.3	31.33
Aspect ratio	2.31	2.31
Mean aerodynamic chord, ft	18.08	18.08
Sweepback of leading edge, deg	60	60
Dihedral (relative to mean thickness line), deg	0	0
Taper ratio (tip chord/root chord)	0	0
Airfoil section	Flat plate	NACA 65-006.5
Vertical tail:		
Area (outside of fuselage), sq ft	76.0	76.0
Height (outside of fuselage), ft	9.36	9.31
Aspect ratio	1.155	1.14
Sweepback of leading edge, deg	60	60
Taper ratio (tip chord/root chord)	0	0
Rudder area, sq ft	15.2	15.5
Rudder chord, ft	1.71	
Airfoil section	Flat plate	NACA 65-006.5
Elevon:		
Type	Plain	
Area (one), sq ft	38.6	38.3
Span (at trailing edge of wing, one), ft	13.7	
Chord (from hinge line to trailing edge), ft	3.05	

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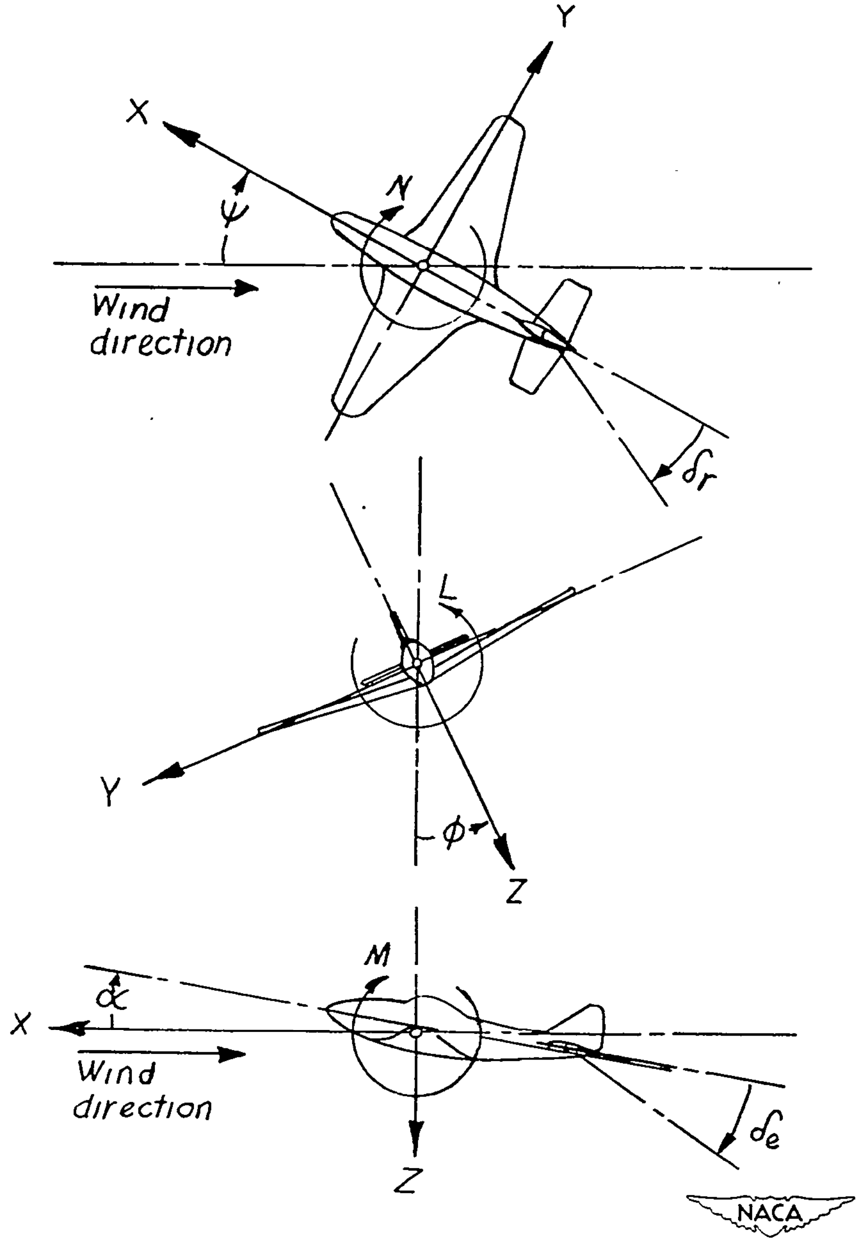

Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having their origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

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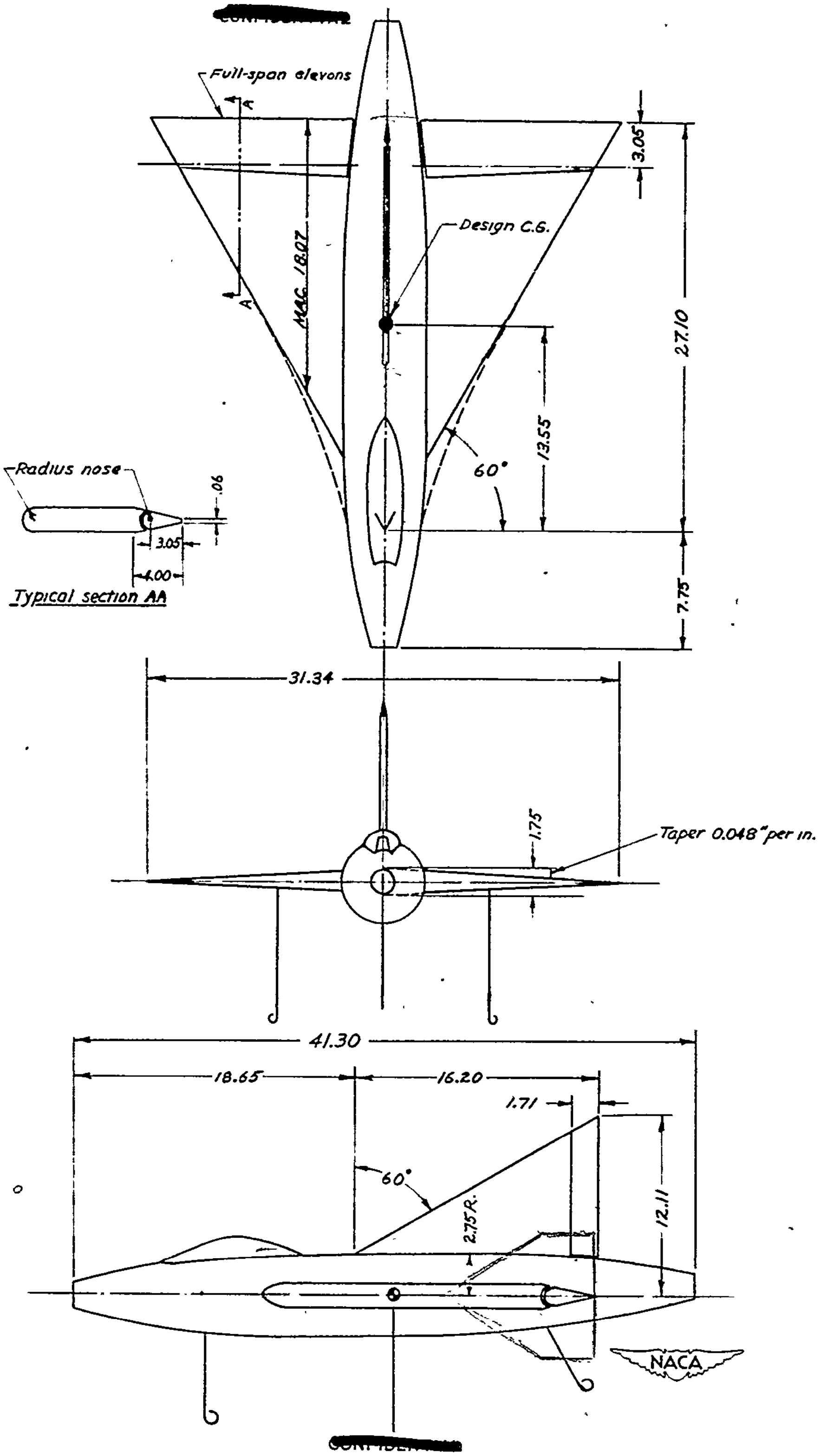

Figure 2.- Three-view sketch of a $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane used in the Langley free-flight tunnel investigation. All dimensions are in inches.

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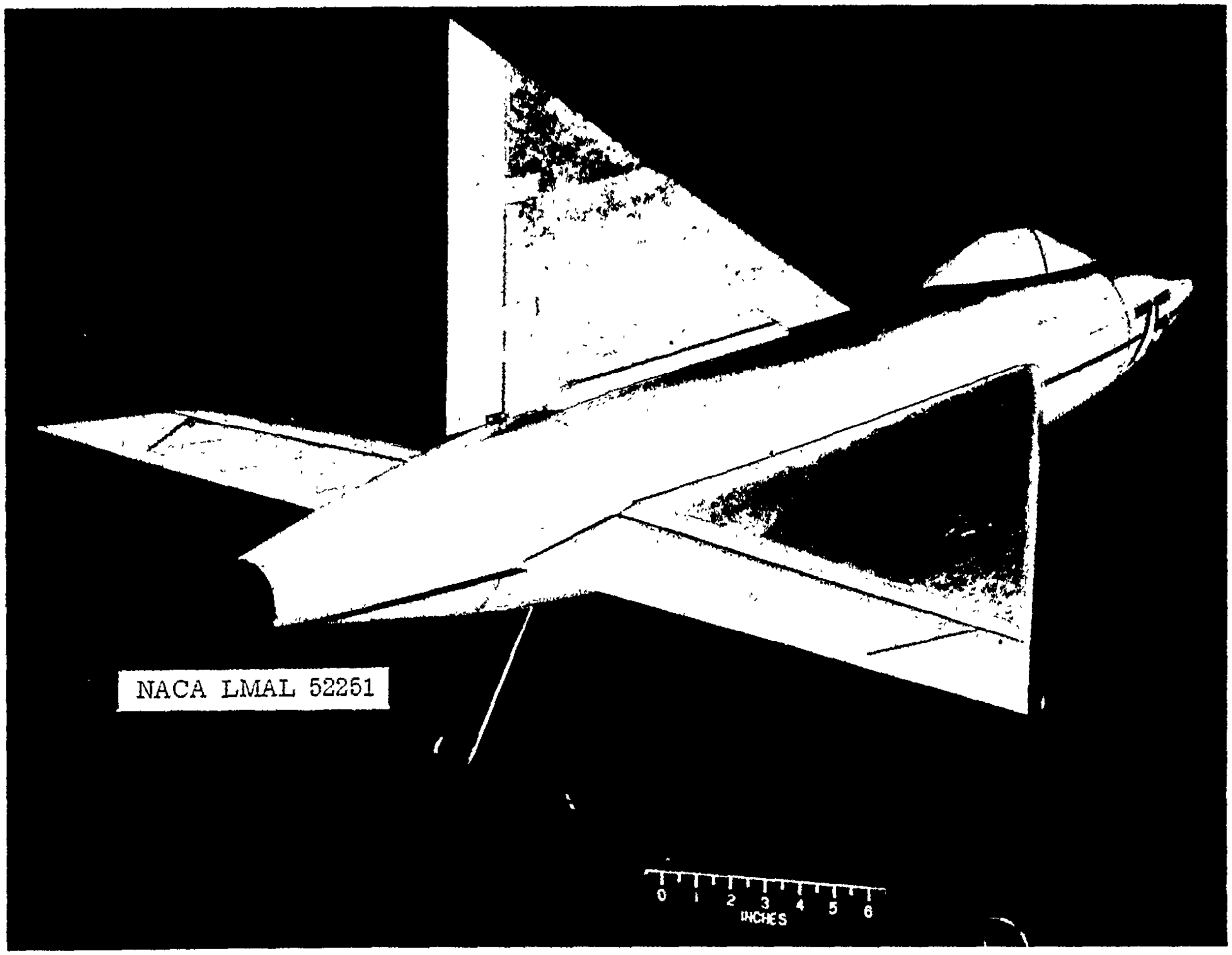

Figure 3.- Three-quarter rear view of $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane tested in the Langley free-flight tunnel.

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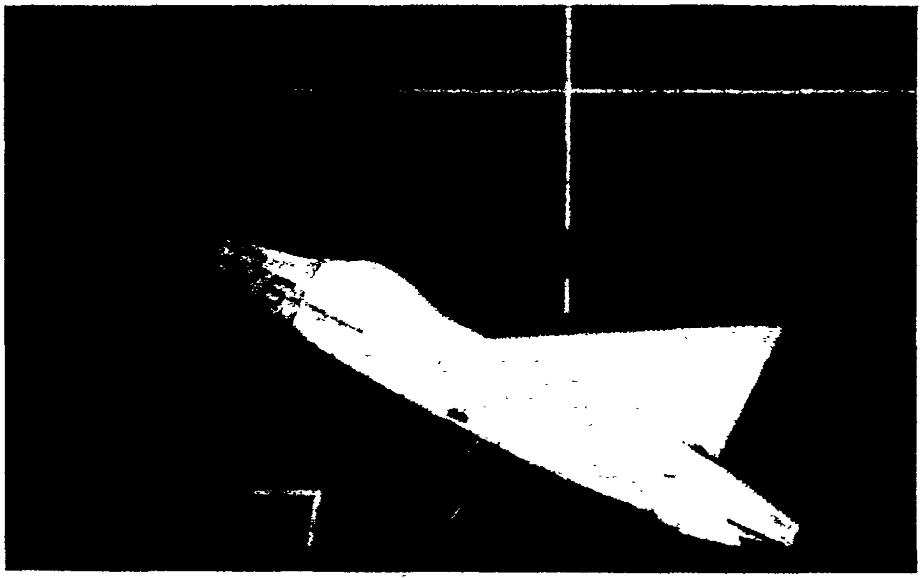
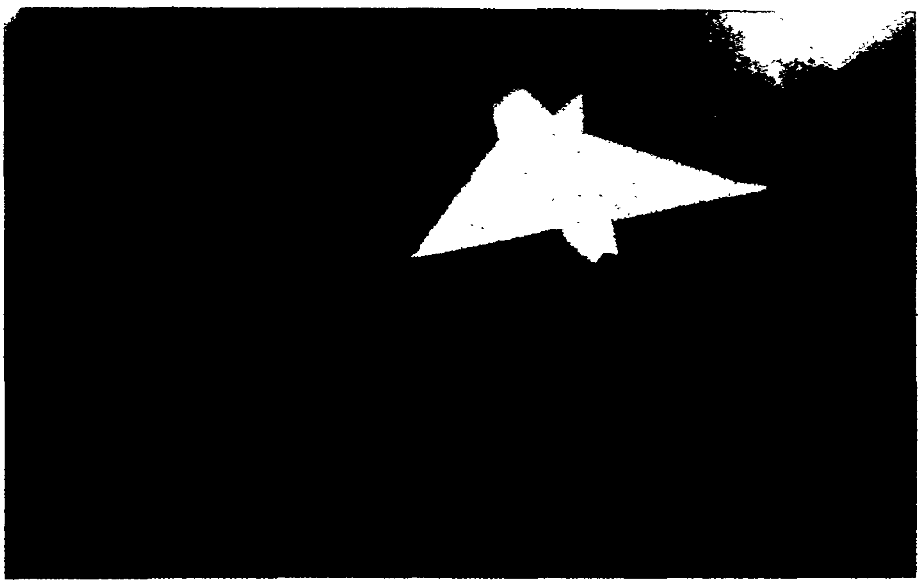


Side view.



Rear view.

Figure 4.- Photographs of the $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane flying in the Langley free-flight tunnel.

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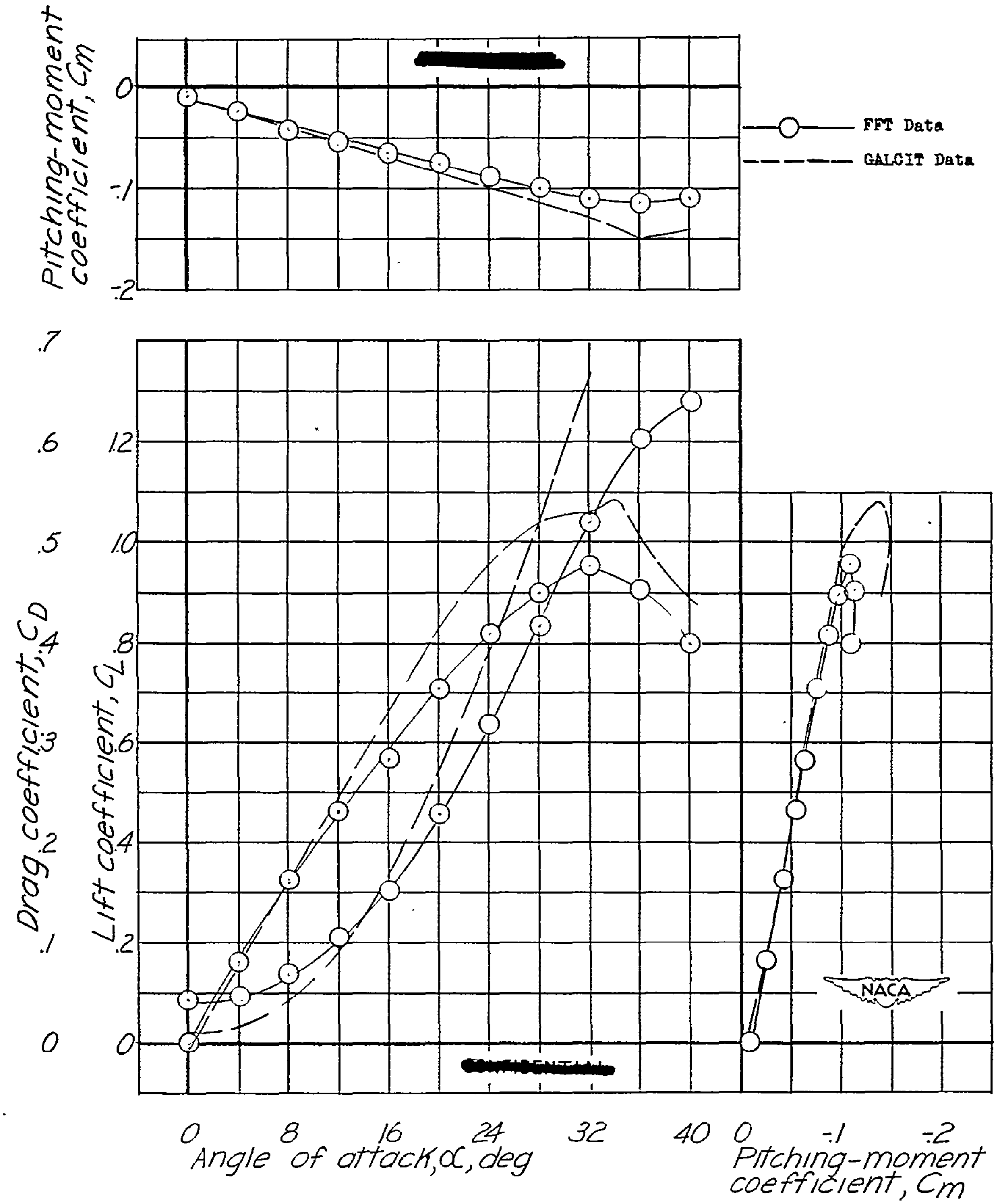

Figure 5.- Comparison of aerodynamic characteristics obtained from Langley free-flight tunnel and GALCIT. $\delta_{e_l} = \delta_{e_r} = 0^{\circ}$.

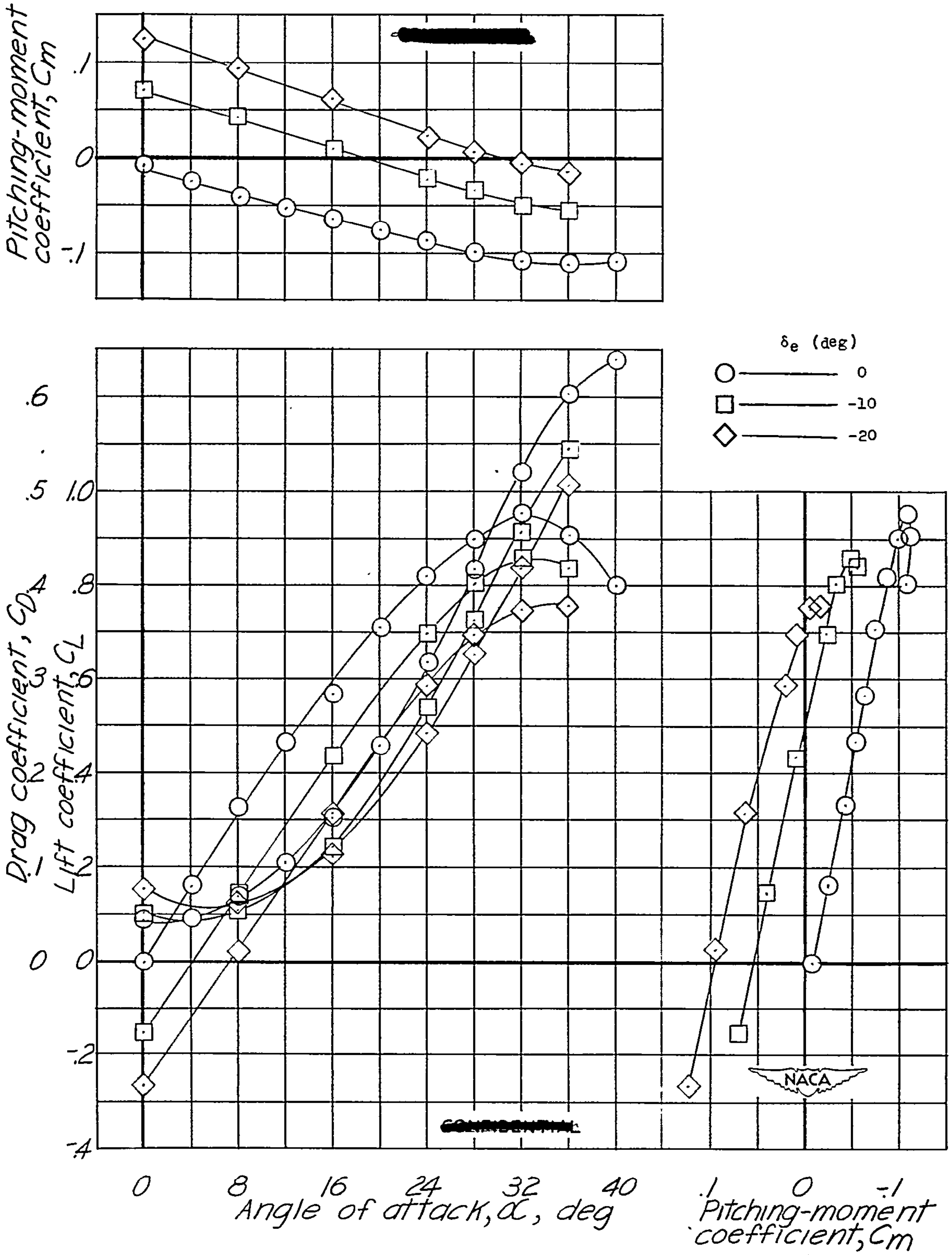

Figure 6.- Effect of elevator deflection on the aerodynamic characteristics of a $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane.

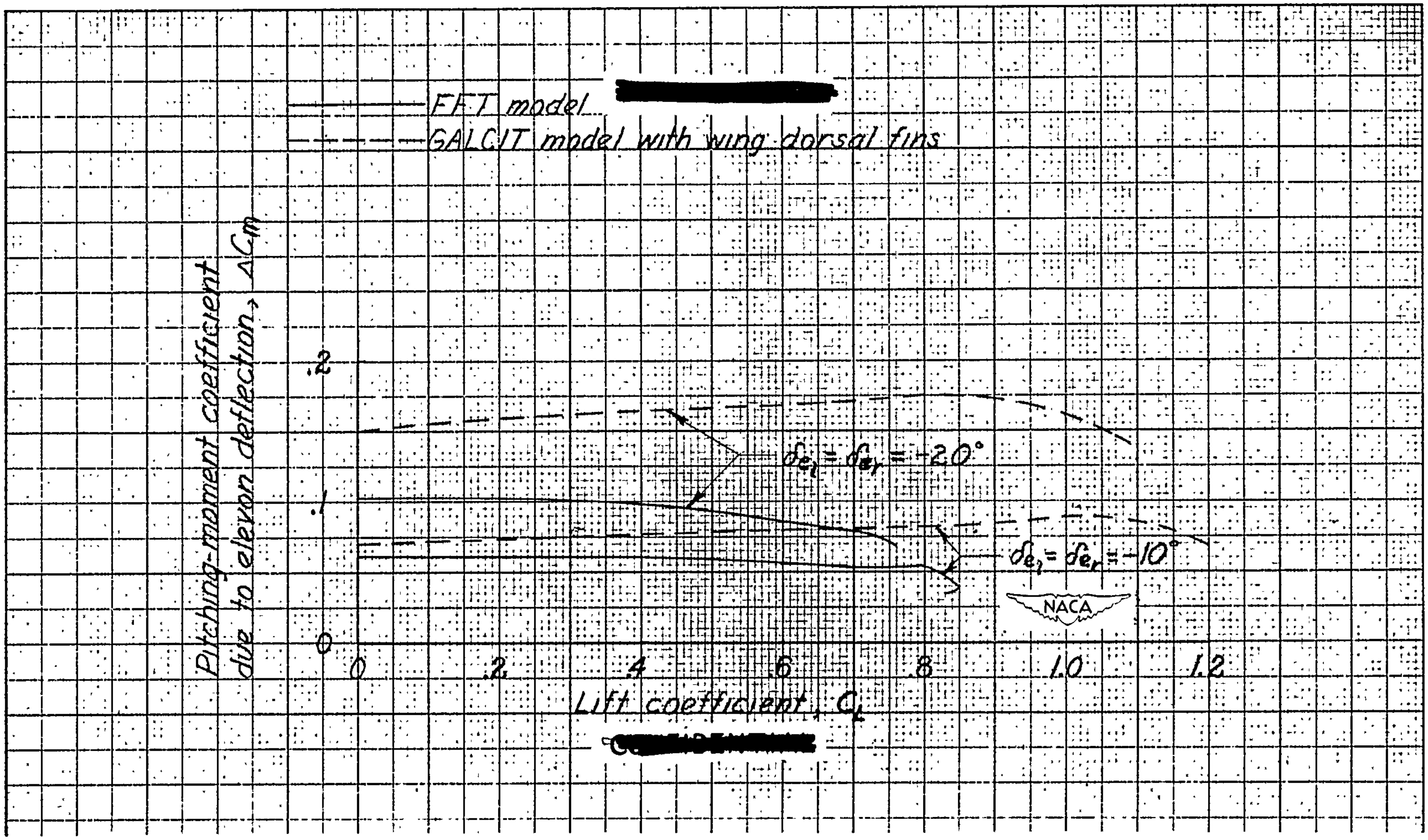

Figure 7.- Variation of elevator effectiveness with lift coefficient for the $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane tested in the Langley free-flight tunnel.

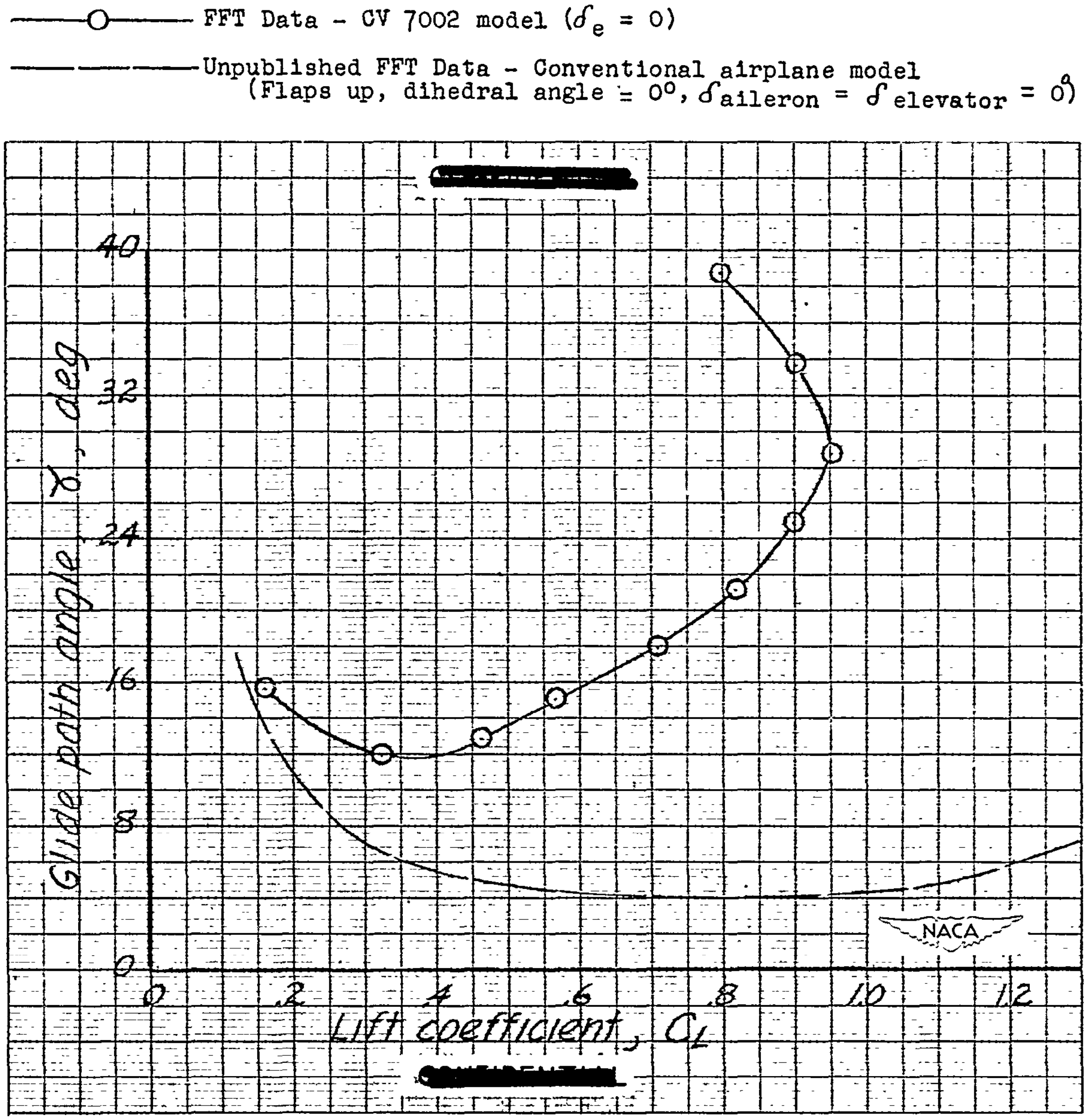

Figure 8.- Comparison of the data for the variation of glide path angle with lift coefficient from force tests on both the $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane and a conventional airplane model tested in the Langley free-flight tunnel. δ_e = 0.

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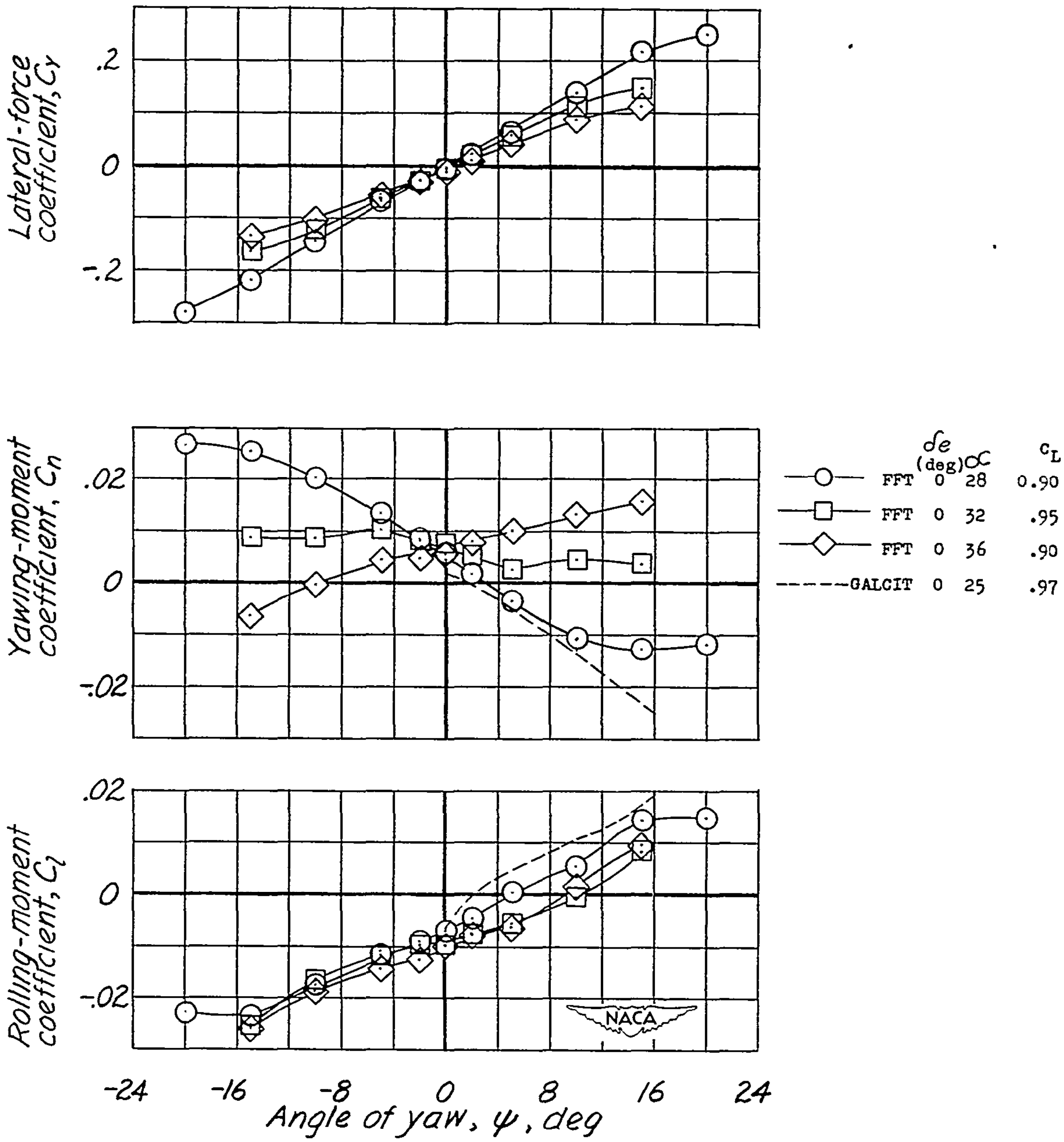

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Figure 9.- Variation of lateral stability parameters with angle of yaw for a $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane.

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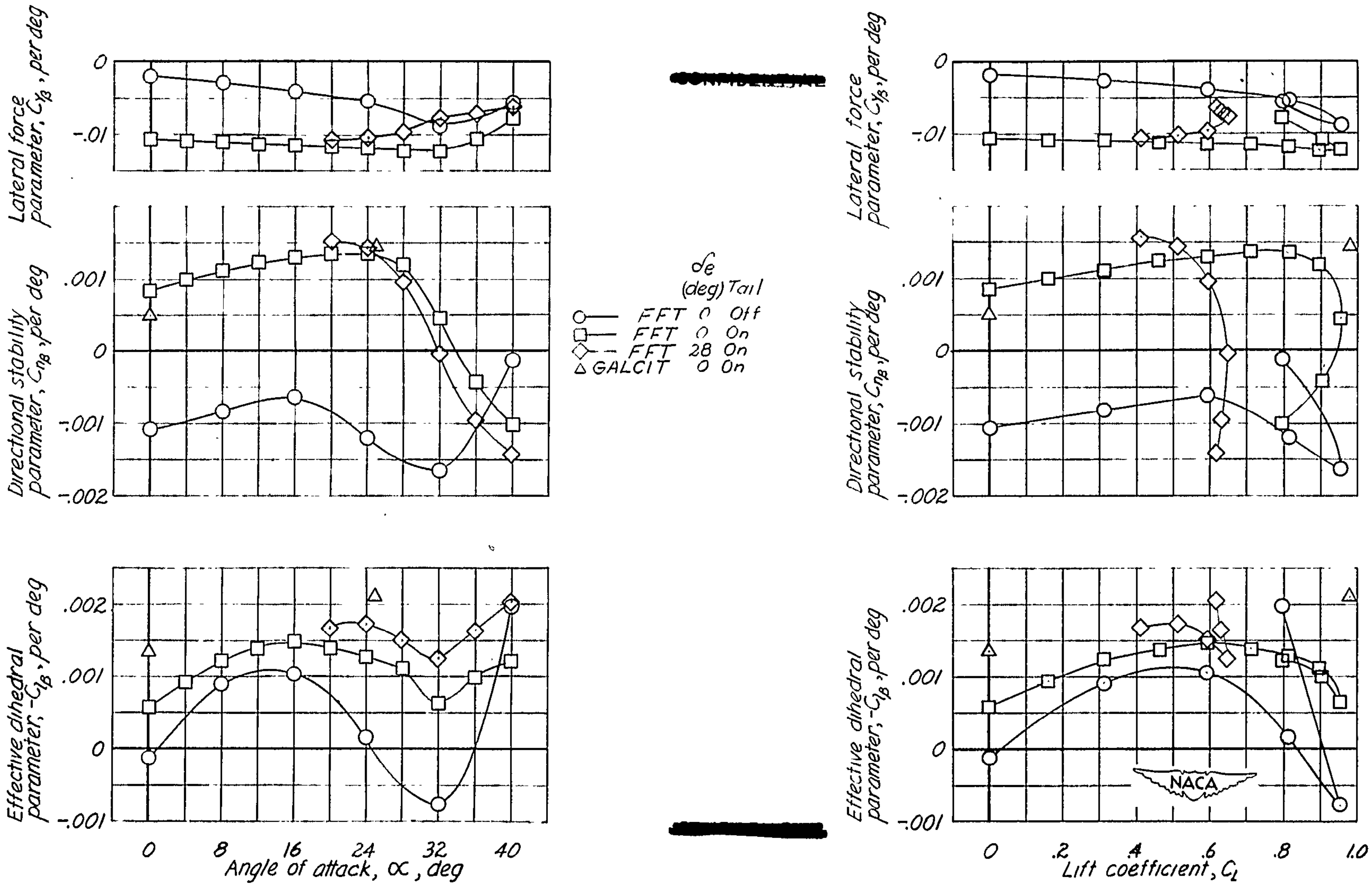

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Figure 10.- Effect of angle of attack and lift coefficient on the lateral stability parameters C_{Y_β}, C_{n_β}, and C_{l_β} for a $\frac{1}{12}$-scale model of the airplane.

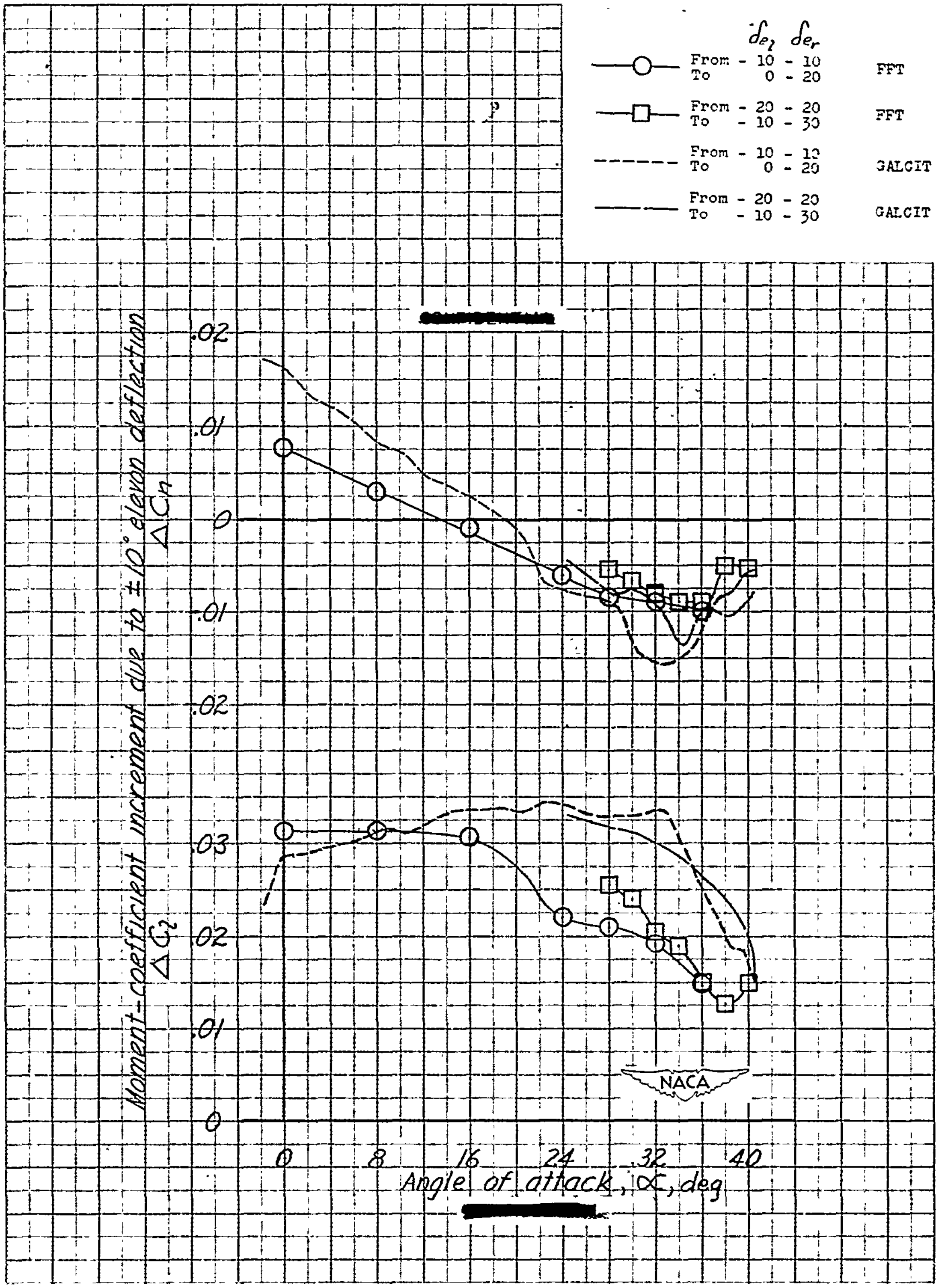

Figure 11.- Variation of aileron effectiveness with angle of attack for the $\frac{1}{12}$-scale model of the Consolidated Vultee 7002 airplane tested in the Langley free-flight tunnel.